

Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversions 2011 Annual Report



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On the cover: Pacific lamprey code 51 passing the counting window in the left fishway at Prosser Dam, July 26, 2011. Photograph from the counting video, courtesy of Jeff Trammell, Yakama Nation Fisheries Program.

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PASSAGE OF RADIO-TAGGED ADULT PACIFIC LAMPREY
AT YAKIMA RIVER DIVERSIONS
2011 ANNUAL REPORT

Andy Johnsen, Mark C. Nelson, and R.D. Nelle

Final Report

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Abstract- The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River and its tributaries. Numbers of adult lampreys returning to the tributaries have declined in recent years due to several contributing factors including hydroelectric and diversion dam operations, habitat degradation, and pollution. The Yakima River has several diversion dams that may be obstacles in the upstream migration of adult Pacific lamprey. Lampreys are known to pass some of these dams but very little is known about their residence times and passage routes. We used radio telemetry to determine approach timing, residence time, fishway routes, other passage routes, and migration rates at the diversion dams on the Yakima River. Wanawish, Prosser, and Sunnyside dams were equipped with telemetry stations. Stations were also established on Satus and Toppenish creeks and near the mouth of the Yakima River. Eight Pacific lampreys, collected at John Day Dam the previous summer, were radio-tagged and released above and below Wanawish Dam on March 30, 2011. Five lampreys made upstream movements and approached at least one dam. Three lampreys were depredated or scavenged by mammalian predators. Upstream movements were made during periods of decreasing discharge and mostly during night hours. Lampreys made first approaches at the dams between April 1 and August 2. One lamprey successfully passed through Wanawish Dam. Two were successful in passing Prosser Dam. One lamprey moved up to Sunnyside Dam but did not pass before the transmitter battery died. For lampreys that passed a dam, total residence time ranged from 29.9 to 81.1 days with fishway passage times between 0.15 and 6.33 days. The average migration rate between dams was 11.35 km/day. Our sample size was small but initial results indicate that while the diversion dams on the Yakima River are passable by adult Pacific lamprey, they appear to be impediments to upstream migration. As the study continues, we will adaptively modify the telemetry stations and tag and release greater numbers of lampreys to gather more detailed information on movements at the dams.

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Introduction

The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River Basin. It is found in many of the same tributaries as other anadromous fishes such as steelhead *Oncorhynchus mykiss* and Chinook salmon *O. tshawytscha*. In comparison to these salmonids, however, relatively little is known about the life history of Pacific lamprey.

Most adult Pacific lampreys return to freshwater from February to June (Kostow 2002). It is thought most do not home to their natal streams, unlike many anadromous fishes, but instead may utilize the “suitable river strategy” in which returning adults are attracted to streams inhabited by larval lamprey or ammocoetes (Waldman *et al.* 2008). Recent genetic studies indicate Pacific lampreys are panmictic (Goodman *et al.* 2008 and Docker 2010) and support the premise of no natal homing in Pacific lamprey.

Much of the information on adult Pacific lamprey migrations in freshwater was gathered by radio telemetry or inferred from counts at dams. Within the Columbia River, most telemetry studies of Pacific lamprey movements have focused on passage at mainstem dams (e.g. Moser *et al.* 2002, Johnson *et al.* 2009, Keefer 2009). These studies documented that hydroelectric dams cause major delays and difficulties for the upstream migration of Pacific lamprey, resulting in less than half of tagged fish successfully passing upstream through the fishways. Radio telemetry studies conducted in tributaries such as the John Day River (Bayer *et al.* 2000), the Willamette River (Clemens *et al.* 2011), and the Methow River (Nelson *et al.* 2009) found that Pacific lamprey entered these spawning tributaries in late summer, moved upstream, and then ceased migration to overwinter downstream of spawning areas before resuming migration in the spring prior to spawning.

Counts in the fishways at dams on the Columbia River have shown a sharp decline in the number of individuals returning to freshwater to spawn since the 1960's (Kostow 2002, DART 2011). Several factors including construction and operation of hydroelectric and diversion dams, river impoundment, water withdrawals, stream alteration, habitat degradation, elevated water temperatures, pollution, and ocean conditions have likely contributed to this decline (Luzier *et al.* 2011).

Pacific lampreys have ecological and cultural importance. Pacific lampreys can be a main dietary source for sea lions and seals as well as avian predators (Roffe and Matte 1984) and thus may act as buffers to predation on salmonids. Spawned out adults are sources of marine derived nutrients in tributaries and ammocoetes may play a major role in nutrient cycling. Native Americans in the Columbia Basin historically fished for Pacific lampreys at falls or rapids that impeded adult upstream migration. Interviews with tribal elders indicate that this once abundant species was utilized traditionally for ceremonial, sustenance, and medicinal purposes but has declined to the point where it is now rarely harvested (Close *et al.* 2001).

Pacific lampreys inhabit the Yakima River Basin (Patten *et al.* 1970) but very few have been counted at Prosser Dam in recent years (DART 2011). Details on upstream migration, timing, spawning, and distribution of Pacific lamprey in the Yakima River are not well understood. Several diversion dams in the Yakima River Basin may be impediments for adults migrating to suitable spawning areas. Adult Pacific lamprey have been observed in the fish ladders at Prosser Dam during the spring and fall months, but specific telemetry studies have not been conducted and little is known about their migration rates or residence time at the dams.

The objective of this radio telemetry study is to determine adult Pacific lamprey passage at the Yakima River diversion dams, including approach timing, residence time downstream of dams, passage routes, time in the fishways, total time spent at the dams, and migration rates between dams. In addition, areas where Pacific lamprey over-winter and spawn in the Yakima River will be located if possible.

This annual report presents the initial results of our study through September 10, 2011.

Methods

Study Area

The Yakima River flows for 344 km, from the headwaters at Keechelus Lake in the Cascade Mountains to the confluence with the Columbia River at river kilometer (rkm) 539, and drains an area of approximately 15,941 km² (Figure 1). Annual mean discharge at the Kiona Gage Station (rkm 48.1) is 3,479 ft³/s (range 1,293 – 7,055 ft³/s), with the highest daily mean discharge of 59,400 ft³/s recorded on December 24, 1933 and the lowest daily mean discharge of 225 ft³/s recorded on April 4, 1977 (USGS 2011). The main tributaries include Satus Creek, Toppenish Creek, Naches River, Taneum Creek, Teanaway River, and Cle Elum River.

A complex irrigation network, managed in large part by the U.S. Bureau of Reclamation, makes the Yakima River basin one of the most intensely irrigated areas in the United States, and has served to make it a leading producer of tree and vine fruit as well as other diverse agricultural products. Six lakes and reservoirs, with a total active storage capacity of 1.07 million acre-feet, hold the spring and summer snowmelt in the mountains for delivery to irrigation districts between April and October (Fuhrer *et al.* 2004). Irrigation water is distributed throughout the network via rivers, creeks, and man-made canals. Irrigation diversion dams include Wanawish, Prosser, Sunnyside, Wapato, Roza, and Easton on the Yakima River and Cowiche and Wapatox on the Naches River (Figure 1).

Surface water diversions are equivalent to about 60 percent of the mean annual stream flow from the basin (Fuhrer *et al.* 2004). In spring, the stream flow reflects the quantity of water stored in the mountain snowpack, while during the dry summer months it reflects the quantity of water released from the basin's storage reservoirs. During summer, return flows from irrigated land account for 50 to 70% of the flow in the lower Yakima River (Fuhrer *et al.* 2004).

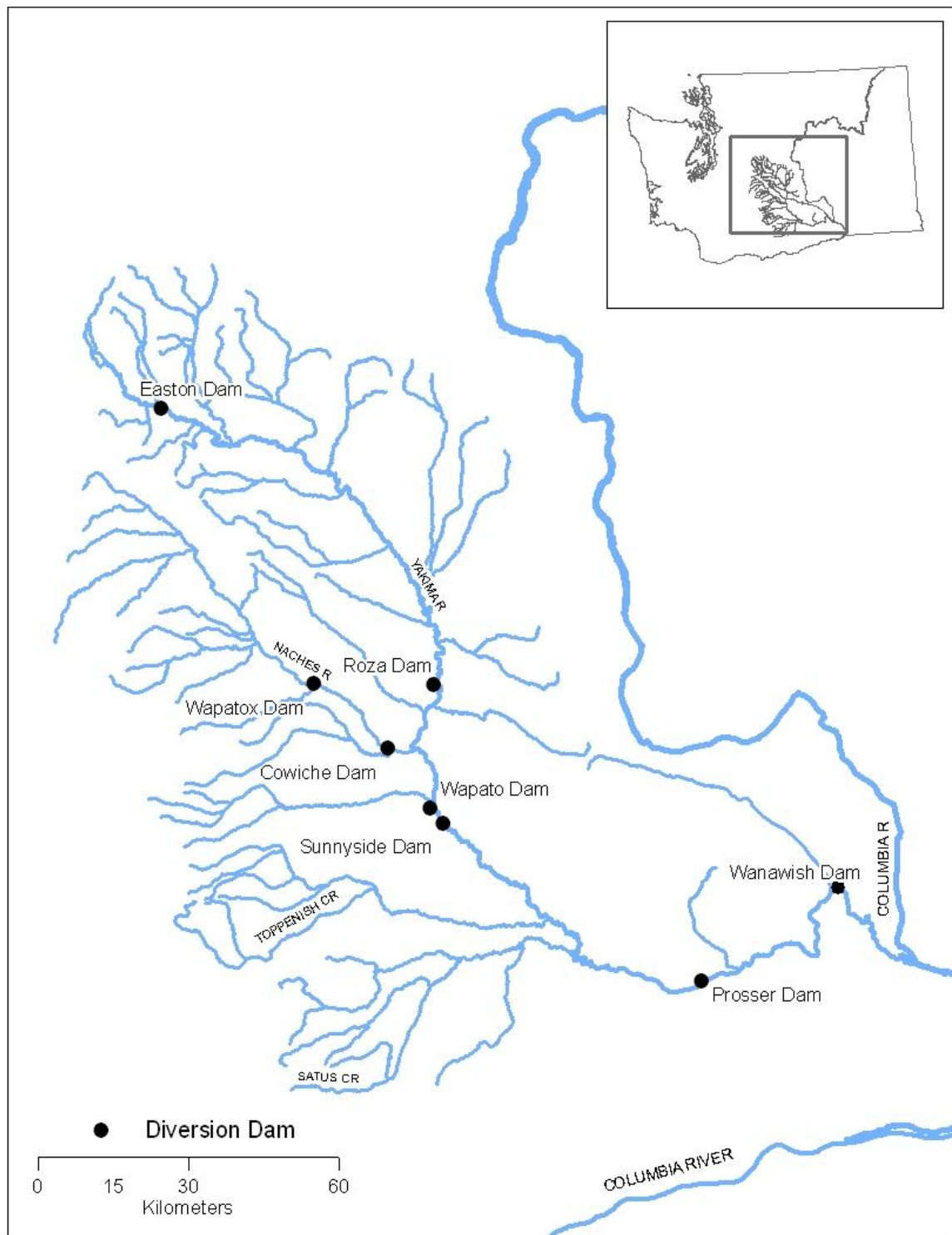


Figure 1. Map of the Yakima River watershed, showing the locations of the major diversion dams.

Fixed Stations

Fixed telemetry stations were set up at three diversion dams, in two tributaries, and near the mouth of the Yakima River (Figure 2). The basic layout at a diversion dam consisted of aerial antennas that monitored downstream of the dam, the face of the dam, and upstream of the dam. Underwater antennas monitored pools at the entrance, middle, and exit of each fishway. Aerial antennas were four-element Yagi-type and underwater antennas were constructed of coaxial cable with 100 mm of the inner wire bared at the end. Aerial antennas were mounted on masts and the underwater antennas were suspended on chains. Data recording telemetry receivers (Lotek SRX-400A), equipped with an antenna switching unit (Grant Engineering Hydra) programmed on a “master-slave” cycle, were housed in a metal box at each station. AC power was used to charge the external 12v battery that powered the receiver at each diversion station. Solar panels were used as a back-up power system in case AC power was lost.

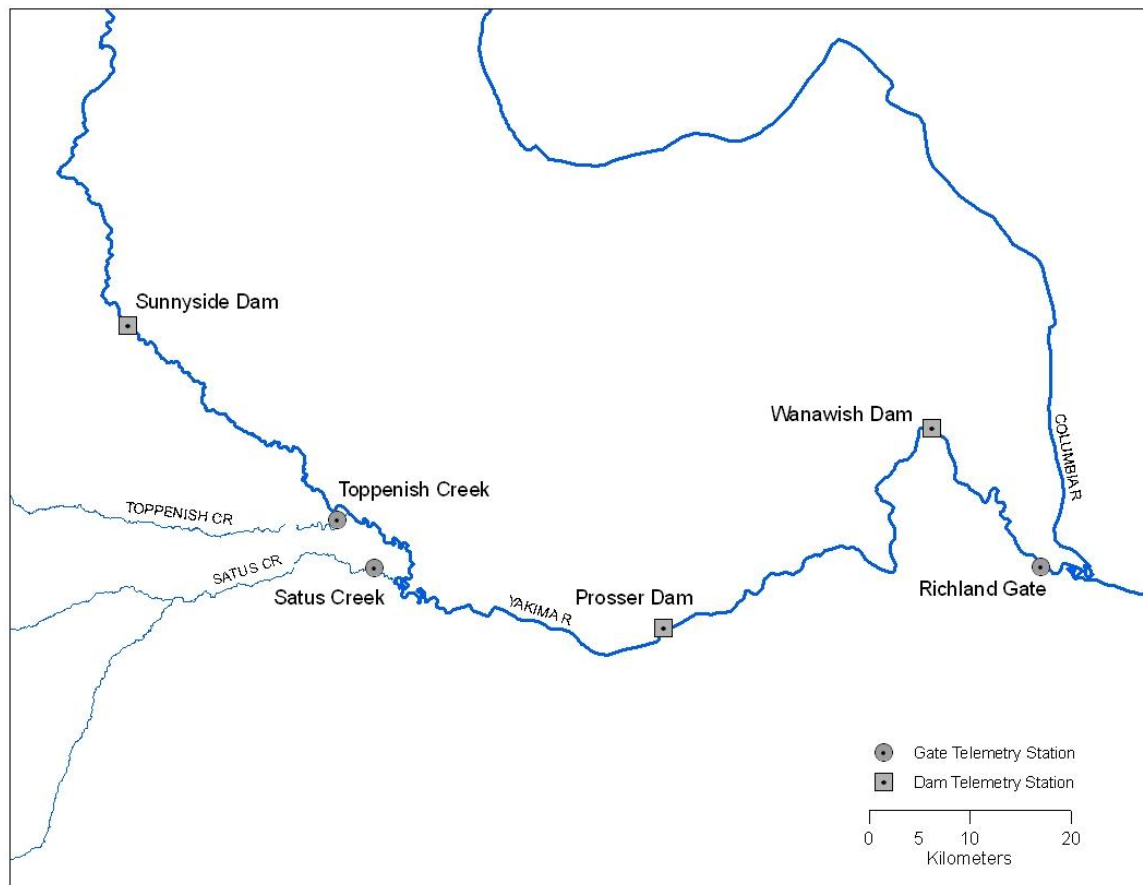


Figure 2. Map of the lower Yakima River basin showing the locations of fixed telemetry stations in 2011.

Wanawish Dam

Wanawish Dam, constructed in 1892 at rkm 29, is a rock filled timber crib dam with a concrete face. It is 160 m long and approximately 2 m high and diverts water into canals on both banks of the river. Fishways, consisting of an entrance pool and 4 vertical slot pools, are located on each bank at the dam, with the fishway exit near the mouth of each canal (Figure 3). Both fishways at the dam had one aerial antenna facing downstream, one upstream, and one across the face of the dam. An underwater antenna was located at the entrance, middle, and exit pool of each fish ladder as well as the entrance to the irrigation canal on river left (Figure 3).

Prosser Dam

Prosser Diversion Dam, constructed in 1904 by private interests and now operated by the U.S. Bureau of Reclamation, is located at rkm 75. The facility consists of a concrete weir structure, an irrigation canal (1,500 ft³/s capacity) on the left bank, three vertical slot type fishways (one on the right bank and two mid-river “islands” on the dam), an adult sampling facility (in the right bank fishway), and a juvenile bypass and sampling facility (downstream at the canal screen structure). The structural height of the dam is 2.7 m and the weir crest length is 201 m (USBOR 2011). The right bank fishway had one aerial antenna monitoring downstream and one upstream; underwater antennas were located at the high water entrance, the low water entrance, the middle, and exit pools of the fish ladder (Figure 4). The center island fishway had one downstream aerial antenna and two upstream aerial antennas (combined as one unit); underwater antennas were at both entrance pools and the exit pool of the fish ladder (Figure 4). The left island fishway was equipped with aerial antennas monitoring upstream, downstream, and across the face of the dam both to the left and right of the island; underwater antennas were located within the entrance, middle, and exit pool of the fish ladder (Figure 4).

Sunnyside Dam

Sunnyside Diversion Dam, located at rkm 167, was completed in 1907. It is a concrete ogee weir with embankment wing and a canal (1,320 ft³/s capacity) on the left bank. The structural height is 2.4 m and the weir crest length is 152 m (USBOR 2011). Fish passage facilities consist of three stair step ladders, one on each bank and one near the center of the dam. The left bank fishway had one upstream aerial antenna and two downstream aerial antennas (combined as one unit); underwater antennas were located in the entrance, center, and exit pool of the fish ladder (Figure 5). The center island fishway was equipped with a total of five aerial antennas: two (combined as one unit) monitored downstream, one monitored the right face of the dam, and two monitored upstream on either side; underwater antennas were located in both entrance pools and a middle pool of the fish ladder (Figure 5). A fixed station was not installed on the right bank fishway due to access issues. The right bank fishway was open, however, it was not maintained or cleaned and it is unknown whether it was passable by lamprey.

Gate Stations

A station near the mouth of the Yakima River (rkm 6.9) was set up to use as “gate” to determine if Pacific lamprey moved out of the study area. This fixed station consisted of one aerial antenna aimed across the river, a SRX400A receiver, and a car battery charged

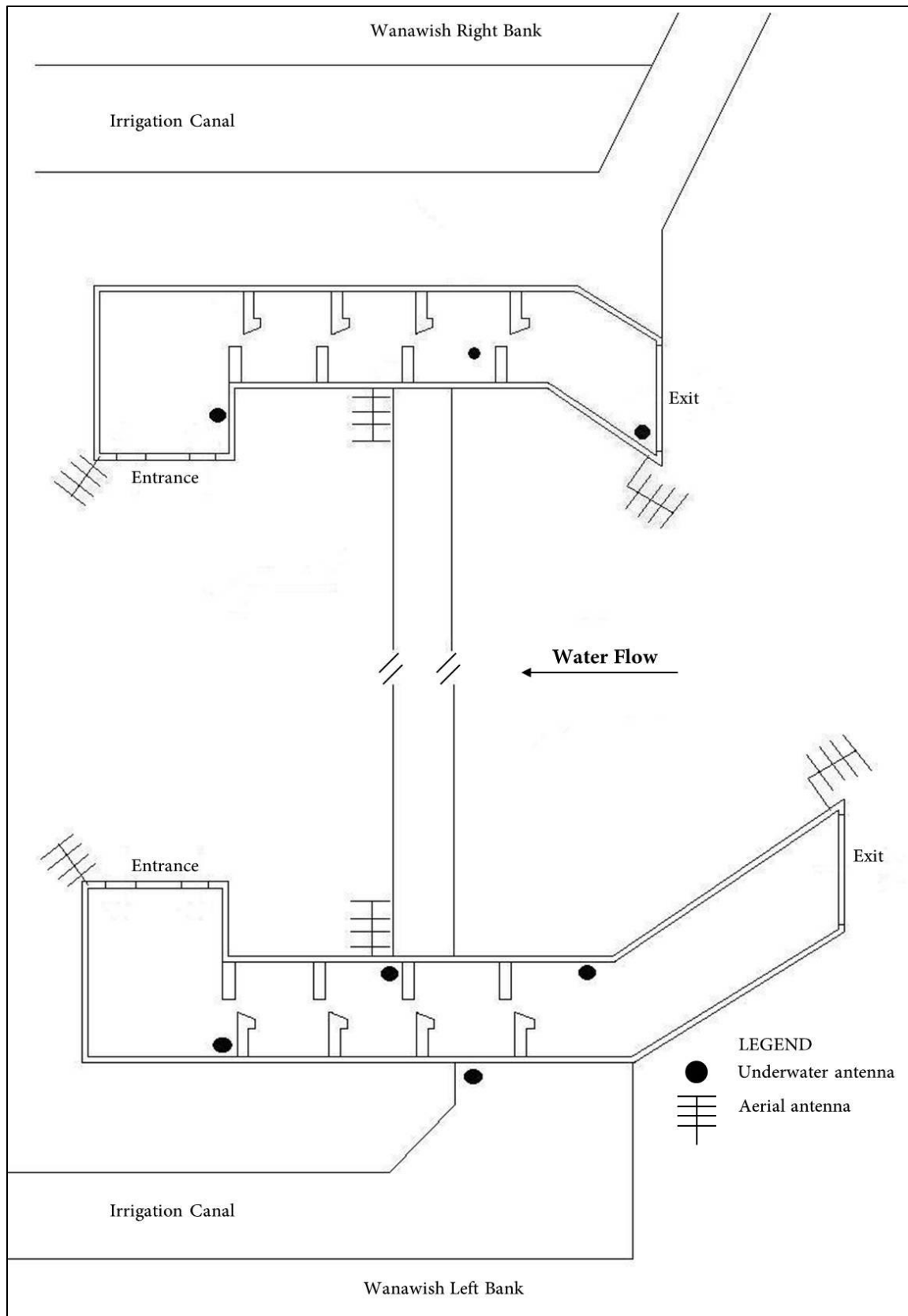


Figure 3. Locations of telemetry antennas on right and left bank fishways at Wanawish Dam, 2011.

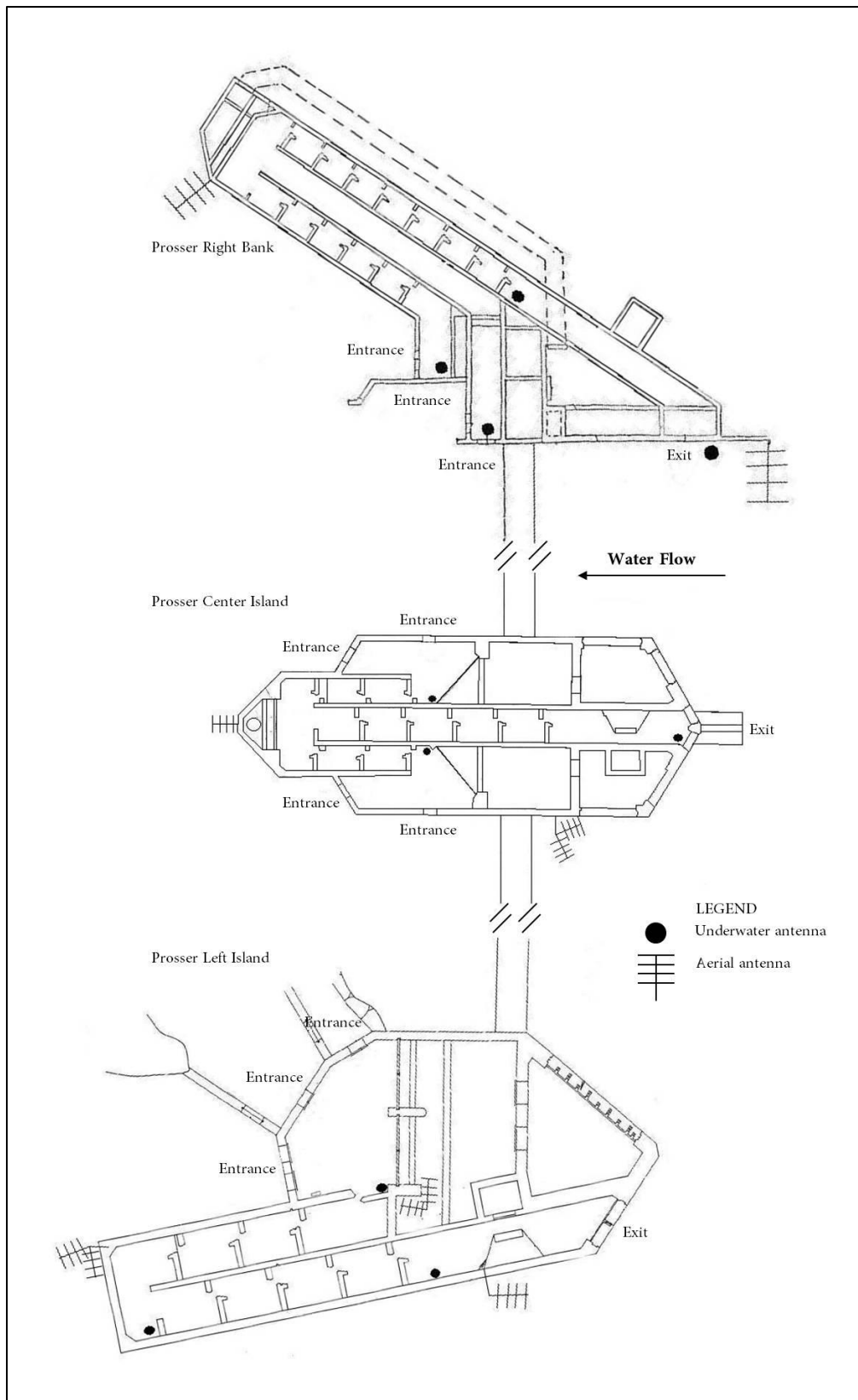


Figure 4. Locations of telemetry antennas on right, center, and left fishways at Prosser Dam, 2011.

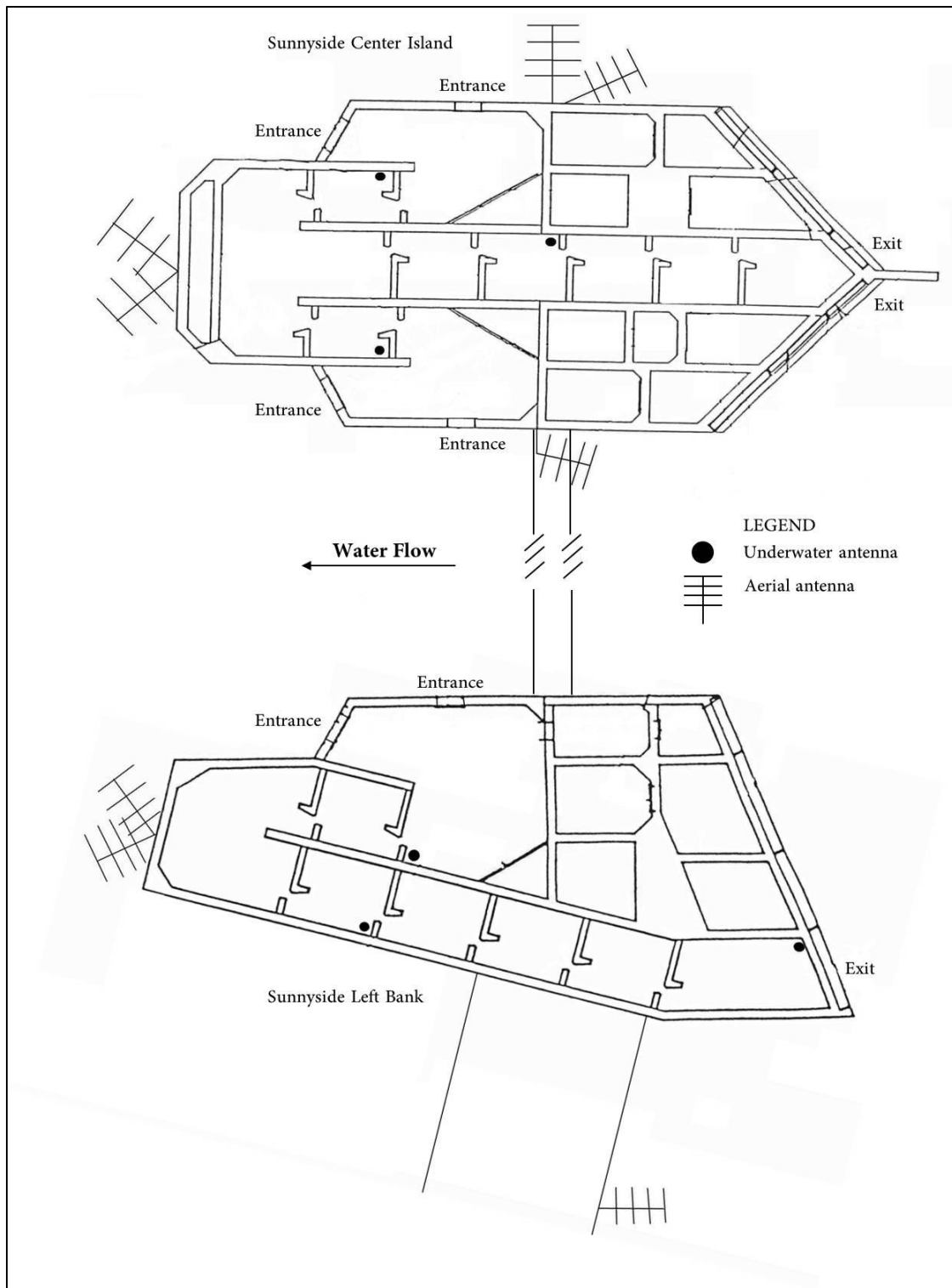


Figure 5. Locations of telemetry antennas on center and left bank fishways at Sunnyside Dam, 2011.

by AC power provided by the landowner. Gate stations were also set up on Satus and Toppenish creeks to determine movement into these tributaries (Figure 2). These stations each had one antenna facing upstream and one facing downstream combined together as one unit. The receivers at these stations were powered by solar panels.

Telemetry Data Analysis

For descriptive purposes, the definitions of *left* and *right* are referenced to the downstream or river flow direction, and apply to the river banks as well as the island fishways at the dams. *First approach* is defined as the first detection recorded on an aerial antenna at a fixed telemetry station. *Below dam residence* is calculated as the difference between the first downstream detection at the dam and the first detection of entry into the fishway during a passage event. *Fishway passage* is calculated as the elapsed time between the first fishway entrance detection and the last fishway exit detection during a passage event. *Above dam residence* at a dam is defined as the difference between the last fishway exit detection and the last upstream aerial antenna detection. *Migration time* is calculated as the difference between the last detection as the lamprey moved from one station to the first detection at the next station. *Migration rate* is defined as migration time divided by the distance between stations.

Collection

Adult Pacific lampreys were supplied by the Yakama Nation Fisheries Program from collections at John Day Dam on the Columbia River (rkm 347) between August 15 and September 21, 2010. Fish were captured in funnel traps at the picketed leads of the fish counting stations on both sides of the dam and held at the Yakama Nation Klickitat Salmon Hatchery facility. On January 30, 2011, they were transferred to the Yakama Nation Prosser Hatchery facility and held until tagged. Prior to being transported between facilities the lampreys were screened for fish health issues by the USFWS Lower Columbia Fish Health Center. One lamprey tested positive for furunculosis. Subsequently all were injected with an antibiotic (0.1 – 0.15 cc of Oxytetracycline) to prevent the spread of disease (Patrick Luke, Yakama Nation Fisheries Program, pers. comm.). At both facilities the fish were held in flow-through metal stock tanks supplied with river water.

Radio Transmitter Implantation

Implantation surgeries took place in the spawning shed at the Yakama Nation Prosser Hatchery facility. The surgical procedure was modified from methods described in Moser *et al.* (2002) and Nelson *et al.* (2007). Tools and transmitters were chemically disinfected with Benz-All®. Fish were anesthetized in a bath of 80 ppm tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate to match the pH of the river water. After 8 to 10 minutes the fish was removed from the bath and total length (mm), interdorsal base length (mm), girth (mm), and weight (g) were measured and recorded. Sex was determined by examining the differences in shape of the dorsal fins (Patrick Luke, Yakama Nation Fisheries, pers. comm.) and later verified by the presence of eggs or testes. The lamprey was then placed on a cradle made from PVC pipe and the head and gills were immersed in a 15 L bath of 40 ppm of buffered MS-222. Wet sponges were placed in the cradle to prevent the lamprey from sliding and to assist in incision

placement. Using a number 12 curved blade scalpel, a 20 mm incision was made 1 cm off the ventral midline with the posterior end of the incision stopping in line with the anterior end of the first dorsal fin. A catheter was inserted through the incision and out the body wall approximately 4 cm posterior to the incision. The antenna was threaded through the catheter and the individually coded radio transmitter (Lotek NTC-4-2L, 8 x 18 mm, 2.1 g, 162 d battery life) was inserted into the incision. Using a 19 mm needle the incision was then closed with 3-4 braided absorbable sutures. The lamprey was then transferred to an oxygenated 600 L recovery tank used for transportation to the release sites. All lampreys were held for a minimum of 1.5 hours before release.

Release

Release sites were located both upstream and downstream of Wanawish Dam. To reduce bias in the approach of fish to the dam, tagged lamprey were released on both sides of the river downstream of the dam. Release sites were chosen by accessibility and relative close proximity to Wanawish Dam. Individuals were chosen for each release site by removing them from the recovery tank at random. The code of each fish was then recorded prior to release.

Tracking

Fixed telemetry stations were downloaded on a weekly schedule. Test beacons were activated during downloads at each station to ensure the antennas and receivers were operating and recording properly. In addition to the data recorded at fixed stations, mobile tracking was opportunistically conducted to determine exact locations at the dams as well as approximate locations between the dams. Mobile tracking was conducted by foot, truck, and boat.

Temperature

Stream temperatures were monitored at Wanawish, Prosser, and Sunnyside dams. Electronic data loggers (HOBO[®] U22 Water Temp Pro v2, Onset Computer Corp.) were calibration checked for accuracy with an NIST-tested thermometer and only units that agreed to within 0.2 °C were deployed. The data loggers were housed in perforated PVC pipe (40 mm dia.) and tethered to wire cable suspended into the river from one fishway at each dam. Data loggers were programmed to record once every hour. Data were downloaded into a shuttle, offloaded, and saved to a desktop computer. Mean, minimum, and maximum daily water temperatures were calculated with the Hoboware[®] Pro software package.

Discharge

Stream discharge was obtained from the USBOR Pacific Northwest Region Hydromet website (<http://www.usbr.gov/pn/hydromet/yakima/yakwebarcread.html>). Average daily flow (QD) was queried for the Yakima River stations at Kiona (KIOW) and Prosser (YRPW). Discharge is reported in cubic feet per second (ft³/s).

Results

Tagging

A total of 8 adult Pacific lampreys were radio tagged on March 30, 2011 (Table 1). Five were female and 3 were male. Weights ranged from 217 to 418 g (mean 347 g), lengths from 520 to 670 mm (mean 601 mm) and girths from 90 to 115 mm (mean 103.5 mm).

Release

On March 30, 2011, all of the tagged lampreys were released in the vicinity of Wanawish Dam. Two lampreys (codes 47 and 54) were released from the left bank 1.2 km upstream of the dam, three (codes 49, 52, and 53) were released from the left bank 2.7 km downstream from the dam and three (codes 48, 50, and 51) were released from the opposite bank (Figure 6). Release locations were along the bank in areas with slower water and cover consisting of submerged grasses or an undercut bank. All lampreys sought cover immediately upon release. Mobile tracking on the following day indicated four lampreys had moved upstream and one downstream.

Table 1. Weight, total length, girth, dorsal base length, sex, and release location of adult Pacific lamprey radio-tagged and released in the Yakima River on March 30, 2011.

Code	Weight (g)	Total Length (mm)	Girth (mm)	Dorsal Base Length (mm)	Sex	Release Location
47	380	610	105	32	F	Upstream
48	217	520	90	13	M	Downstream Right
49	313	550	95	15	F	Downstream Left
50	418	670	109	20	M	Downstream Right
51	372	628	105	32	M	Downstream Right
52	377	606	113	20	F	Downstream Left
53	372	611	115	15	F	Downstream Left
54	325	616	96	25	F	Upstream

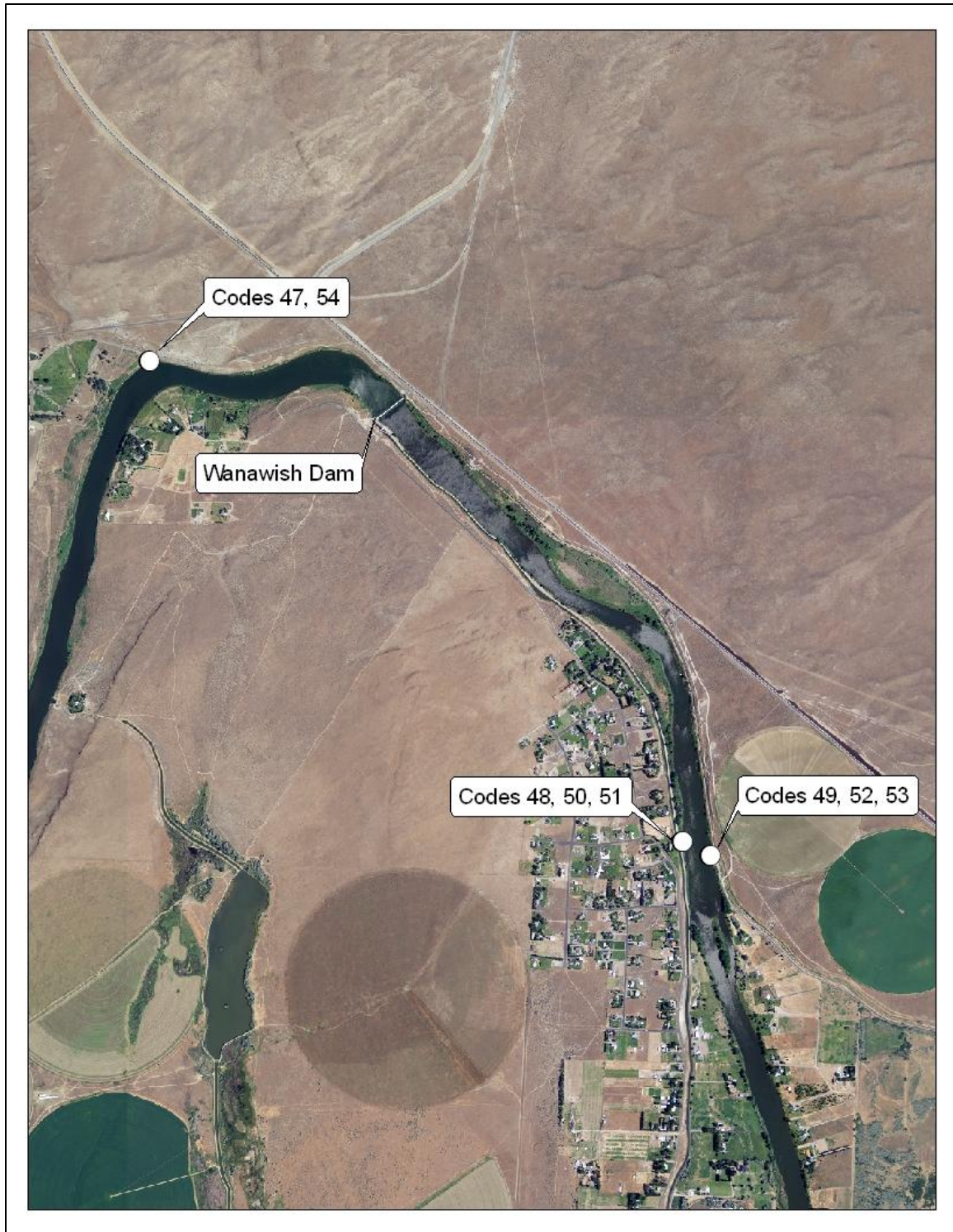


Figure 6. Aerial photograph of release locations of radio-tagged adult Pacific lamprey released in the vicinity of Wanawish Dam on March 30, 2011.

Movements

Six of the eight radio-tagged Pacific lampreys (75%) eventually moved upstream, including 4 of the lamprey released below the dam and both that were released above the dam. Two of the lamprey released below the dam did not move and evidence indicated both were depredated, most likely by otters. Five of the 8 (63%) approached one or more of the dams. The number of days between release and first approaching one of the dams ranged between 2.2 and 42.5 days. Two of the lampreys that approached Wanawish Dam did not pass the dam but instead moved back downstream; one of these exited the Yakima River. The movements of tagged lamprey at each dam are described in the following sections.

Wanawish Dam

First Approach - Tagged lamprey approached Wanawish Dam from April 1 to May 4, 2011 (Table 2). All four lampreys were first detected at the left bank station on the downstream aerial antenna. Three of these fish were recorded on the right bank station within 3 hours as they moved from left to right along the dam. The fourth was recorded on the left bank station for nearly 20 days before it moved close enough to the right bank station to be detected.

Table 2. Wanawish Dam approach and residence data: first and last downstream detection dates and number of days that adult radio-tagged Pacific lamprey resided below the dam during spring, 2011.

Code	1 st Station Detected	1 st Downstream Detection Date	Last Downstream Detection Date	Days	Enter Fishway?
48	Left bank	04/10/2011 21:29	05/19/2011 14:41	38.7	No
50	Left bank	04/01/2011 20:36	04/08/2011 11:48	6.6	No
51	Left bank	04/01/2011 22:14	04/03/2011 05:43	1.3	Yes
53	Left bank	05/04/2011 21:52	05/05/2011 07:38	0.4	No

Below Dam Residence- The residence time at Wanawish Dam before entering the fishway was 1.3 days for code 51 (Table 2). Codes 53 and 48 approached Wanawish Dam but then moved back downstream and had residence times of 0.4 and 38.7 days, respectively. Code 50 approached the dam and had a residence time of 6.6 days before the tag was located, but not recovered, along riprap in a hole that appeared to be a mink den, indicating the lamprey was likely depredated or scavenged.

Shortly after first arriving at Wanawish Dam codes 48 and 50 were detected on the left bank fishway entrance antenna but neither entered the fishway. Both lampreys resided near the face of the dam until they moved to the other bank. Shortly after code 50 moved to the right bank it was detected on that fishway entrance antenna and may have briefly entered the fishway before it moved a short distance downstream, where it was detected by the aerial antenna until depredated. Code 48 remained near the face of the dam while detected on the right bank, particularly on the right edge of the dam face, until it moved downstream and ultimately exited the Yakima River.

Fishway Passage- Only one of the four lampreys definitely entered a fishway at Wanawish Dam (Table 3). The right bank fishway was used by lamprey code 51 to pass upstream of the dam. It took 19 minutes for this fish to navigate from the entrance antenna to the exit underwater antenna, but it then remained in the exit pool of the fishway for several days. The total time from entrance to exit of the fishway was 6.3 days. During this time, the exit trash rack was not cleaned and had accumulated a considerable amount of debris which may have affected the behavior of the lamprey in the fishway. Stream discharge was high during the time code 51 resided in the ladder and could also have altered its behavior.

Table 3. Wanawish Dam fishway data: dates of entry, exit and total time in fish ladder for radio-tagged adult Pacific lamprey during spring, 2011.

Code	Fishway	Enter Ladder	Exit Ladder	Time in Ladder
51	Right	04/03/2011 05:43	04/09/2011 13:41	6.3 d

Above Dam Residence- After exiting the fishway at Wanawish Dam, code 51 entered the right bank Columbia Irrigation District Canal, where it stayed just downstream of the canal entrance for 22.2 days. It then continued migrating upstream. Code 47, released upstream of the dam, moved upstream and was last located near Benton City at rkm 38 on May 4.

Prosser Dam

Two tagged lampreys were detected at Prosser Dam. Code 54 took 42.5 days to reach Prosser Dam after it was released upstream of Wanawish Dam. However, code 54 remained near its release location through at least May 4 so its actual travel time to Prosser Dam was less than 8 days. Code 51 was released downstream of Wanawish Dam and after passing that dam and leaving the canal, took 4.2 days to reach Prosser Dam.

First Approach- The two lampreys that approached Prosser Dam were detected on May 6 and May 12, 2011 (Table 4). Code 51 was first detected on the left station and code 54 on the center station.

Table 4. Prosser Dam approach and residence data: first and last dates of detection and number of days that radio-tagged adult Pacific lamprey resided below the dam during spring and summer, 2011.

Code	1 st Station Detected	1 st Downstream Detection Date	Last Downstream Detection Date	Days	Enter Fishway?
51	Left	05/06/2011 00:13	07/25/2011 23:25	80.9	Yes
54	Center	05/12/2011 01:14	06/28/2011 03:06	47.1	Yes

Below Dam Residence- The residence times at Prosser Dam before passing a fishway were 47.1 and 80.9 days (Table 4). Both lampreys were detected on downstream aerial antennas and at entrance antennas several times before navigating a fishway. Movements along the entire length of the dam occurred, but both lampreys resided the majority of the time near the left bank, where flow over a notch formed more white water than along the rest of the face (Figure 7).



Figure 7. Whitewater area where two adult radio-tagged Pacific lampreys were usually located during the day while residing below Prosser Dam during spring and summer, 2011.

Code 54 was detected outside the entrances to all three fishways on multiple occasions, indicating it was exploring back and forth across the face of the dam and near the ladders before it finally passed. It was first detected at, but did not enter, the right entrance of the center island fishway on May 13, and then during the next several weeks, it was detected several times outside both side entrances to the center ladder, outside the left island fishway entrance, and outside the right bank fishway high water entrance. On June 20, it entered the left fishway and was briefly detected on the underwater antenna in pool number 4 before it descended. On June 23, it briefly entered the right bank fishway high water entrance pool and on June 28, it re-entered that entrance and ascended the ladder.

Code 51 was detected at the left fish ladder entrance of the center island fishway on May 19 but did not enter the ladder. It was also detected at the entrance to the left island fishway on June 20 but it did not enter that ladder until July 25, when it finally passed. Code 51 was never detected at the right bank fishway.

Fishway Passage- Lamprey code 54 entered the right bank fishway on June 28 and navigated the ladder in 21.9 hours but was not recorded by the video camera in the counting window. Lamprey code 51 entered the left fishway on July 25 and navigated the ladder in 3.5 hours (Table 5) where it was recorded by the video camera in that counting window.

Table 5. Prosser Dam fishway data: dates of entry and exit and total time in the fish ladder for radio-tagged adult Pacific lamprey during summer, 2011.

Code	Fishway	Enter Ladder	Exit Ladder	Time in Ladder
54	Right bank	06/28/2011 03:06	06/29/2011 01:02	21.9 h
51	Left	07/25/2011 23:25	07/26/2011 02:58	3.5 h

Above Dam Residence- Both lampreys quickly moved upstream after passing Prosser Dam and were only briefly recorded on the upstream antennas. Code 51 migrated to Sunnyside Dam, but the location of code 54 could not be determined after it passed Prosser Dam.

Untagged lampreys at Prosser Dam- Eight untagged and one tagged Pacific lamprey were recorded by the video cameras at the counting windows in the fishways at Prosser Dam between May 11 and September 10, 2011 (Figure 8). Code 54 was not observed passing the counting window and was not counted.

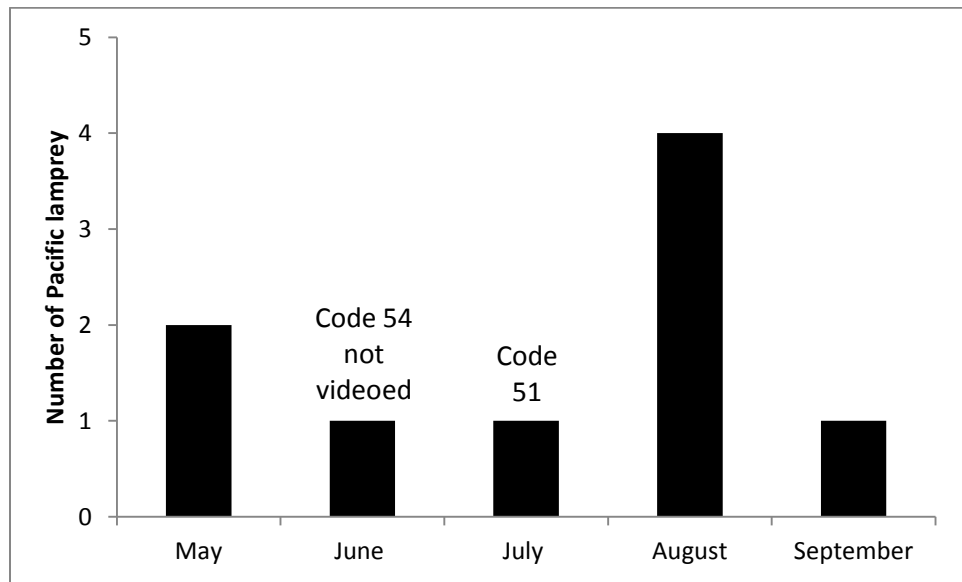


Figure 8. Video counts of adult Pacific lamprey at Prosser Dam, May - September, 2011.

Sunnyside Dam

First Approach- Lamprey code 51 approached Sunnyside Dam on August 2 at 21:47. It was first detected on the aerial antenna on river left of the center island fishway station. During the next two hours it moved from the left side of the island fishway to the right side and then back to the left side.

Below Dam Residence- Code 51 resided at the downstream face of Sunnyside Dam near the corner formed by the left side of the center island and the dam. It was detected for 34 days until the transmitter battery died on September 5, 2011.

Fishway Passage- Lamprey code 51 did not enter the fishway before the battery died.

Above Dam Residence- Code 51 was not detected passing Sunnyside Dam before the transmitter battery died.

Diurnal Period of Movement

Movements of Pacific lamprey between fixed stations occurred almost exclusively at night (Figure 9). All initial approaches to the dams and movements into the fishways were made during night. Movement out of the fishway at Wanawish Dam by code 51 was done during daylight hours. Codes 48 and 53 moved back downstream from Wanawish Dam during daylight.

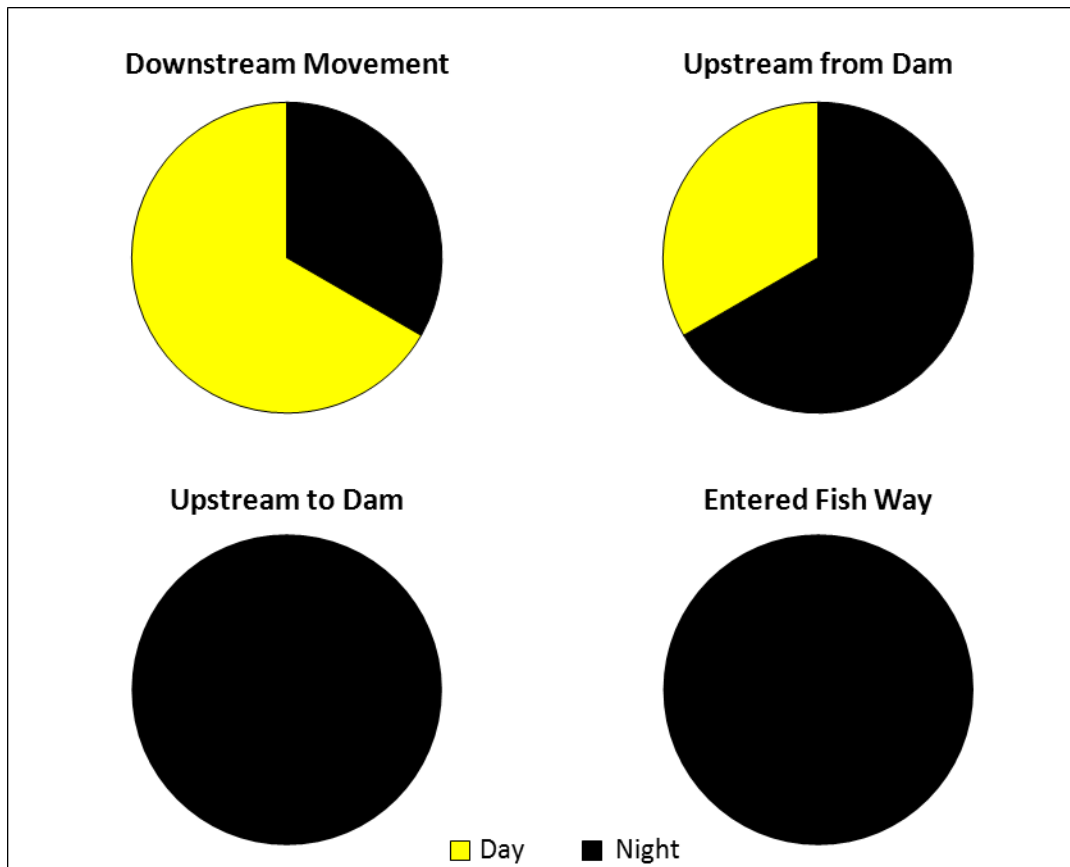


Figure 9. Diurnal periods that adult radio-tagged Pacific lamprey were active during downstream movement, upstream movement, and entry into fishways during spring and summer, 2011.

Migration Rates between Stations

After passing a fish way and leaving a dam, code 51 moved very quickly to the next dam. It took 4.2 days to migrate the 46.7 km from Wanawish Dam to Prosser Dam for an average migration rate of 11.11 km/d. From Prosser Dam to Sunnyside Dam, a distance of 91.4 km, it took 7.91 days for an average migration rate of 11.56 km/d. Only one lamprey (code 48) moved downstream from Wanawish Dam past the RG station and it took 26.49 days to travel that 22.5 km, for an average rate of 0.85 km/d.

Temperature

The temperature loggers were deployed at the three dams and began recording data on June 23, 2011. At Prosser Dam, mean daily stream temperatures ranged from 15.5 °C to 17.7 °C during the time code 54 resided at the dam and ranged from 15.5 °C to 22.2 °C when code 51 resided there. At Sunnyside Dam, mean daily stream temperatures ranged from 16.1°C to 18.6 °C during the time code 51 was present.

Discharge

Stream discharge appeared to influence the movements of radio-tagged lampreys (Figure 10). During high discharge periods, lampreys resided below the dams. Code 51 moved upstream through the fishways and migrated between the dams when discharge was low. Code 54 remained near its release site upstream of Wanawish Dam until it moved upstream during low flow on May 4, prior to peak flows in spring. The two lampreys (codes 48 and 53) that did not pass Wanawish Dam instead moved downstream when discharge increased to peak flow.

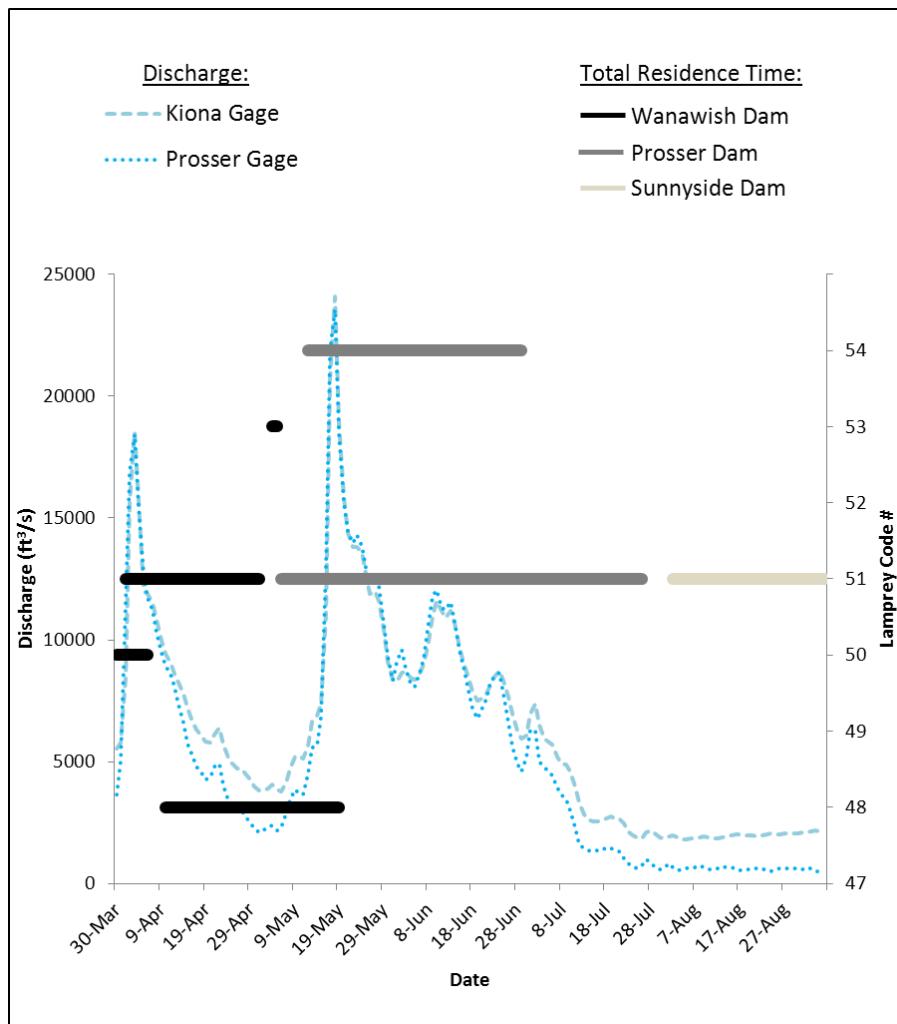


Figure 10. Chart showing the relationship between stream discharge and total dam residence time of radio-tagged adult Pacific lamprey at diversion dams in the lower Yakima River during spring and summer, 2011.

Discussion

The spring release of tagged Pacific lamprey was the beginning of our study of their movements at diversion dams in the lower Yakima River. Fewer lampreys were available for tagging than planned, but this first phase served as a successful pilot to guide future release and monitoring strategies, and demonstrated that our study design is adaptive. Although just 8 lampreys were released at only one dam, a considerable amount of information was obtained. Most of the lampreys moved upstream, suggesting that the behavior of lampreys collected in the Columbia River and released in the Yakima River is similar to the behavior of lampreys voluntarily entering the river. The telemetry arrays at the fixed stations were proofed and we verified that accurate, useful information was recorded. The initial telemetry data allowed us to tune the arrays and add additional antennas where needed. The apparently high predation rate at Wanawish Dam indicates we need to release a greater number of tagged fish at each site than we had planned. The paired downstream/upstream releases of tagged lamprey provided both test and control treatments of their movements at the dam but the low passage rate, combined with the relatively high predation rate, indicated we need to release more lampreys. For the fall release, we have 42 transmitters available and plan to release 21 tagged lampreys each at Wanawish and Prosser dam, with a design of 16 released below each dam and 5 above.

Our spring-release sample size was small, but the initial results of Pacific lamprey behavior at the lower Yakima River diversion dams allow a preliminary comparison with other telemetry studies. Keefer *et al.* (2009) and Moser *et al.* (2005) found that less than 50% of radio-tagged Pacific lampreys successfully pass a hydroelectric dam on the lower Columbia River. Main-stem Columbia River dams are much larger and more complex, but our results show that the small diversion dams on the Yakima River are similarly impeding the migration of Pacific lampreys. Only 1 of the 4 Pacific lampreys that approached Wanawish Dam successfully passed upstream. At Willamette Falls Dam on the Willamette River, a lower Columbia River tributary, Clemens *et al.* (2011) also found a passage rate of less than 50%. Interestingly in our study, both lampreys that approached Prosser Dam successfully passed it, but we do not know what the impacts of the long delay was on their reproduction. Spawning areas and timing have not yet been located or described in the Yakima River.

Video counts in the fishways at Prosser Dam indicate that Pacific lamprey pass upstream primarily during the spring, mostly in April and May, and secondarily during the late summer and fall. Our tagged lamprey arrived at Prosser Dam in May but did not successfully pass the dam until June and July. Only one untagged lamprey was counted during June, but lamprey code 54 was not videoed or counted when it passed through the right bank fishway on June 28th. Apparently this lamprey found a route in the ladder that bypassed the video area and indicates that some lampreys are passing the fishways at the dam without being detected and counted.

Counts from this year to date showed passage at Prosser Dam occurred between the months of May and September. In most years since counting began in 2002, the majority of lamprey passed in April and none passed in late June and July. The later summer

passage by both tagged and untagged fish in 2011 may be due to the higher than normal discharge that occurred; it also could be due to a source and/or tagging effect in our study fish.

We modified our original telemetry station design due to environmental factors as well as movements of the lamprey. The discharge this year was higher than normal and caused the AC power to be turned off at the diversion dams for safety reasons. Our receivers therefore lost power, so we added solar panels as backup in the event of another outage. We also added an additional receiver and aerial antennas at Prosser Dam to increase detections of movements along the river left face of the dam where the lamprey held for extended periods of time. We plan to modify the attachments and raise the station boxes to ensure they will not be flooded during high water events in the future. We found that truck surveys had low detection rates because the distance of roads from most of the river usually exceeded the detection capability of our mobile system. We also found that boat tracking was inefficient and too labor intensive to employ for regular surveys. Therefore, we will explore the feasibility of aerial surveys to track radio-tagged lampreys between the dams, and in conjunction with boat surveys, determine overwintering and spawning areas.

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Literature Cited

- Bayer, J., T. Robinson, and J. Seelye. 2000. Upstream migration of Pacific lampreys in the John Day River; behavior, timing, and habitat use. Technical Report, Project No. 200005200, 46 electronic pages, (BPA Report DOE/BP-26080-1).
- Clemens, B.J., M.G. Mesa, R.J. Magie, D.A. Young, and C.B. Schreck. 2011. Pre-spawning migration of adult Pacific lamprey, *Entosphenus tridentatus*, in the Willamette River, Oregon, U.S.A. Environ Biol Fish DOI 10.1007/s10641-011-9910-3.
- Close, D., A. Jackson, J.S. Bronson, M. Fitzpatrick, G. Feist, B. Siddens, H. Li, C. Schreck, C. Lorion, M. Powell, J. Faler, J. Bayer, J. Seelye, D. Hatch, A. Talbot, R. Hooff, C. Beasley, and J. Netto. 2001. Pacific Lamprey Research and Restoration Project. Project No. 1994-02600, 196 electronic pages, (BPA Report DOE/BP-00005455-1).
- Docker, M. 2010. Microsatellite analysis on Pacific lamprey along the west coast of North America. Report *submitted to* U.S. Fish and Wildlife Service, Arcata, CA.
- Fuhrer, G.J., J.L. Morace, H.M. Johnson, J.F. Rinella, J.C. Ebbert, S.S. Embrey, I.R. Waite, K.D. Carpenter, D.R. Wise, and C.A. Hughes. 2004. Water quality in the Yakima River Basin, Washington, 1999-2000. U.S. Geological Survey Circular 1237, 34 p.
- Goodman, D.H., S.B. Reid, M.F. Docker, G.R. Haas, and A.P. Kinziger. 2008. Mitochondrial DNA evidence for high levels of gene flow among populations of a widely distributed anadromous lamprey *Entosphenus tridentatus* (Petromyzontidae). J. Fish Biology 72: 400-417.
- Johnson, E. L., C. A. Peery, M. L. Keefer, C. C. Caudill, and M. L. Moser. 2009. Effects of lowered nighttime velocities on fishway entrance success by Pacific lamprey at Bonneville Dam and fishway use summaries for lamprey at Bonneville and the Dalles Dam, 2007. Technical Report 2009-2 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland, Oregon.
- Keefer, M.L., C.T. Boggs, C.A. Peery, and M.L. Moser. 2009. Adult Pacific lamprey migration in the lower Columbia River: 2007 radiotelemetry and half-duplex PIT tag studies. Technical Report 2009-1 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland, Oregon.
- Kostow, K. 2002. Oregon lampreys: natural history status and problem analysis. Oregon Dept. of Fish and Wildlife.

- Luzier, C.W., H.A. Schaller, J.K. Brostrom, C. Cook-Tabor, D.H. Goodman, R.D. Nelle, K. Ostrand, B. Streif. 2011. Pacific lamprey (*Entosphenus tridentatus*) assessment and template for conservation measures. U.S. Fish and Wildlife Service. Portland, Oregon. 282 pp.
- Moser, M.L., A.L. Matter, L.C. Stuehrenberg, and T.C. Bjornn. 2002. Use of an extensive radio receiver network to document Pacific lamprey (*Lampetra tridentata*) entrance efficiency at fishways in the Lower Columbia River, USA. *Hydrobiologia* 483:45-53.
- Moser, M.L., D.A. Ogden, and C.A. Peery. 2005. Migration behavior of adult Pacific lamprey in the lower Columbia River and evaluation of Bonneville Dam modifications to improve passage, 2002. U.S Army Corps of Engineers, Portland, OR.
- Nelson, M. C, A. Johnsen, and R. D. Nelle. 2009. Adult Pacific lamprey migrations in the Methow River, WA. Draft report November 6, 2009. U.S. Fish and Wildlife Service, Leavenworth Washington.
- Patten, B.G., R.B. Thompson, and W.D. Gronlund. 1970. Distribution and abundance of fish in the Yakima River, Wash., April 1957 to May 1958. U.S. Fish and Wildlife Service Special Scientific Report- Fisheries No. 603. Washington, D.C.
- Roffe, T.J. and B.R. Mate. 1984. Abundances and feeding habits of pinnipeds in the Rogue River, Oregon. *Journal of Wildlife Management*. 48(4):1262-1274.
- U.S. Bureau of Reclamation. 2011. Yakima Project Data. Available online at: http://www.usbr.gov/projects/Project.jsp?proj_Name=Yakima%20Project&pageType=ProjectDataPage#Group284070
- Waldman J., V. Grunwald, and I. Wirgin. 2008. Sea lamprey *Petromyzon marinus*: an exception to the rule of homing in anadromous fishes. *Biol Lett* 4:659–662.